

# Change in Hardness and Microstructure during Cumulative Heating of Tool Steel H13

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## Background

### Hybrid Die

High-cycle production of die casting

Reduction of cooling time by hybridizing copper with die steel  
Accelerated Cooling

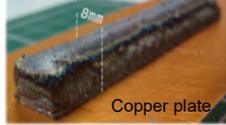
### Laser Metal Deposition (LMD)

- ✓ High Building Speed
- ✓ Dissimilar Materials



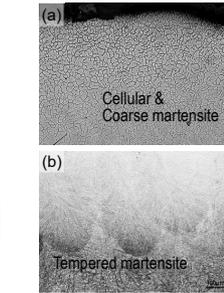
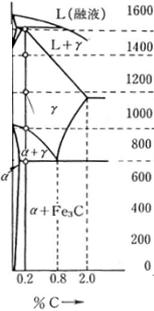
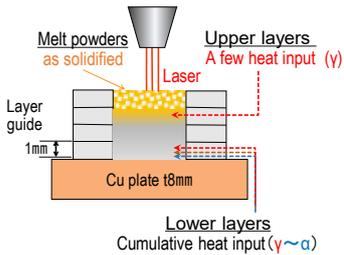
### AM for Hybrid Die

H13 (JIS SKD61)



Laminated deposit 1mm × 7 layers

### Heat Affection during LMD



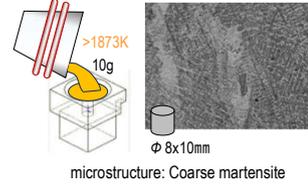
Microstructures of deposited H13 in (a) upper layer, (b) lower layer

## Experimental

### Sample Preparation

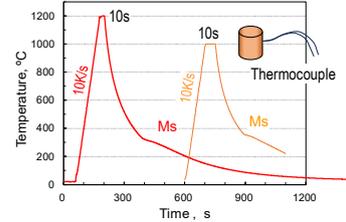
	C	Si	Mn	Cr	Mo	V	Fe
H13	0.4	1.0	0.40	4.9	1.2	1.0	Bal.
LCS	0.3	0.1	1.6	1.9	1.0	0.6	Bal.

### Starting "as-depo" material

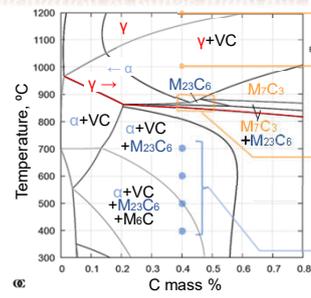


microstructure: Coarse martensite

### Cumulative heat treatment



### Calculation of phase diagram



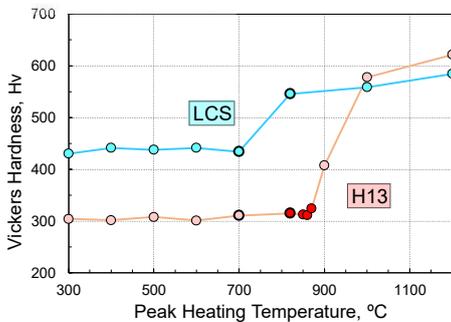
- 1st heating to  $\gamma$   
1200°C × 10s A.C.
- 2nd heating to  $\gamma + VC$   
1000°C × 10s A.C.
- 3rd heating to critical temp.  
820 ~ 850°C × 10s A.C.
- $\alpha \rightarrow \gamma$  transformation and  $M7C3 / M23C6$  precipitation
- Heating to  $\alpha + \text{carbides}$   
700, 600, ... 300°C

## Objective

- Relation between hardness change and microstructure during cumulative heating of tool steel H13 and low-Cr, Si modified steel investigated
- Softening with descending peak temp. interpreted by thermodynamic calculation

## Results and Discussion

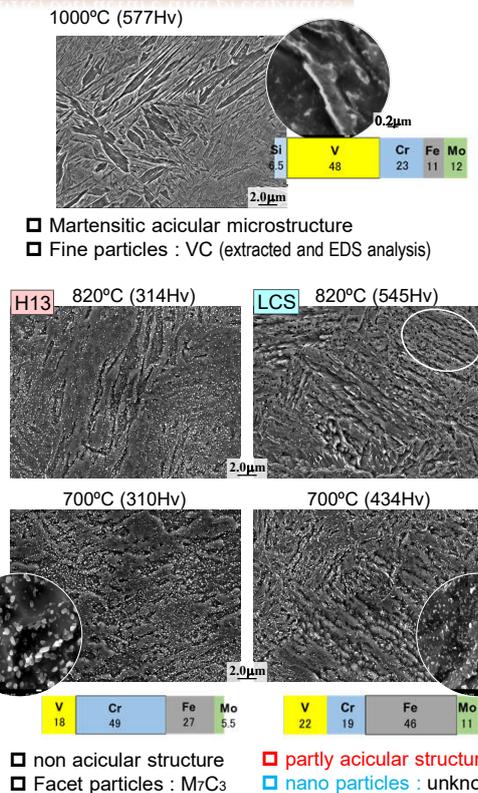
### Change in hardness



Change in hardness of as-depo samples after the cumulative heating at peak temperatures from 1473K to 573K.

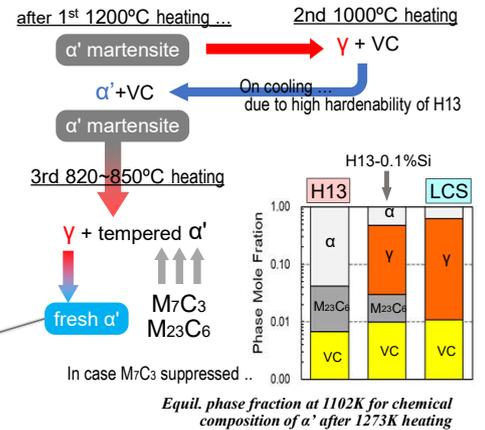
- 600Hv above 1000°C equivalent as-Q
- H13 discontinuous Hv decrease after 820°C
- LCS still high Hv after 820°C, no further softening after 700°C

### Microstructure and precipitates



- non acicular structure
- partly acicular structure
- Facet particles :  $M7C3$
- nano particles : unknown

### Reverse transformation



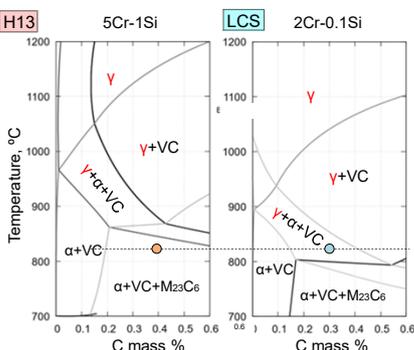
- Low Si or low Cr promotes  $\alpha' \rightarrow \gamma$  transformation in cumulative heating

### Driving force for carbide prec.

fresh  $\alpha'$   
≥ 700°C heating  
Supersaturated or tempered  $\alpha'$

	LCS
$M7C3$	351.9
$M23C6$	92.2
$M3C$	571.9
$M6C$	—
$M3C2$	542.0

Driving force (J/mol) for carbide precipitation from superheated  $\alpha'$  on heating to 973K



Metastable phase diagram for (a) H13 and (b) LCS with the calculation condition of  $M7C3$  suppressed.

## Conclusion and Future Work

- In the cumulative heatings, as-depo samples showed a discontinuous decrease after heated to 1093K for SKD and 973K for LCS. The degree of softening was larger in SKD than in LCS.
- In low-Cr or low-Si tool steels, partial  $\gamma$  transformation took place on heating, which suppressed softening by formation of fresh martensite and precipitation of nano-scale particles.